SOIL RESIDUE EFFECTS OF SELECTED PRE-EMERGENCE HERBICIDES AS MEASURED BY THE GROWTH OF KANOTA OATS

by

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INTRODUCTION

Increased use of pre-emergence herbicides for selective weed control in agriculture has resulted in the need for a better understanding of the interaction between herbicidal chemicals and the soil properties. The question of most concern is the length of toxic life of the soil residues of herbicides and their effect upon crops planted following herbicide application as well as upon weeds.

The relative life spans of toxic soil residues have been determined for many of the older general soil sterilants, contact herbicides and for some of the earlier developed pre-emergence chemicals, but most of the new highly selective organic pre-emergence herbicides remain untested. The primary objective of this study was to determine the toxic life of the soil residues from eight pre-emergence herbicides as measured by their effects on the growth of a bioassay plant, the oat (*Avena sativa* L., Kanota). A secondary objective was to observe growth modifications and reactions of the oat to these herbicidal soil residues.

REVIEW OF LITERATURE

The first use of a pre-emergence herbicide was reported in 1947 (25). At this early point in selective weed control development, a pre-emergence herbicide was considered to be a chemical applied to the soil after a crop had been seeded, but prior to its emergence. While the early definition is still valid, the term is now generally used to refer to the stage of growth of the weed. For the purpose of this study, pre-emergence herbicide has been defined as a chemical applied to the soil prior to the emergence of the weed.

For effective weed control pre-emergence herbicides must be applied to the soil. Just as the environment of the aerial plant parts influence the behavior of contact herbicides, soil factors influence the availability and the action of herbicides applied to the soil. Sheets and Danielson (23) have reported that factors affecting the action of herbicides in the soil include (a) microbial action, (b) volatilization, (c) adsorption by mineral colloids and organic matter, (d) leaching, (e) chemical reaction, (f) photodecomposition, and (g) absorption by plants.

Microbial action is considered the major pathway of herbicide detoxification. Most organic herbicides are subject to microbial decomposition if environmental factors favor growth and proliferation of microorganisms. Sheets and Danielson (23) reported that 2-chloro-4,6-bis(diethylamino)-s-triazine (chlorazine) became more toxic with elapse of time for several months following application to the soil, and that this increase in toxicity was retarded if the soil was sterilized in an autoclave prior to chemical treatment. The increase in toxicity was considered to be the result of microbial action removing one or both of the amino groups.

All herbicides are volatile to some degree, and this can be beneficial or detrimental to their herbicidal action. Vapors of 2,4-dichlorophenoxyacetic acid (2,4-D) and 4,6-dinitro-O-sec-butylphenol (DNBP) have been known to cause extensive damage to crops not sprayed with the herbicide, but subject only to vapors arising from the surface of treated soils (23).

Adsorption of herbicides by the soil varies greatly with its composition (7). Organic matter has been found to be responsible for the greatest amount of herbicide adsorption in soils, but mineral colloids can also adsorb certain herbicides. In most soil systems adsorbed herbicides are gradually

lost from the soil through the reduction of their concentration in the soil solution, leaching, chemical and biological degradation, and absorption by plants (23).

Leaching is a primary factor in the persistence of some specific herbicides, but the low solubility of most organic pre-emergence chemicals, restricts the leaching action on them. The extent of adsorption by the soil particles, amount of rainfall or irrigation and texture of the soil are all major factors governing the extent of leaching. The soil pH and molecular size of the herbicidal chemical also govern the extent to which some specific herbicides undergo movement in the soil (23).

Chemical reaction and photodecomposition are relatively unexplored or of little importance in the persistence of most of the present herbicides (23). Sheets (20) reports that pH of the soil may affect the solubility of certain herbicides or affect the charge on organic molecules. One group of chemicals is applied to the soil in a relative non-phytotoxic form and converted by the soil to highly phytotoxic herbicides. The pathways of chemical conversions and reactions in the soil are still unsolved due to the difficulty in isolating the active systems, but the key to the action of pre-emergence herbicide action may be in such processes.

Absorption by plants is an important factor in the loss of certain herbicides from the soil (23). While this factor is not as important as microbial action, removal and decomposition of herbicides by plants and subsequent translocation of the metabolic products to aerial portions could account for the removal of variable quantities of pre-emergence herbicides.

Fundamental studies have been reported for 2-chloro-4,6-bis(ethylamino)-s-triazine (simazine) and most of the studies reported prior to 1959 have

been reviewed by Sheets (20). The phytotoxicity of simazine has been reported by Sheets to be directly related to temperature (20). Burnside and Behrens (7) have indicated a highly significant interaction between simazine application rates and temperature increase. These workers have also found a highly significant interaction between simazine phytotoxicity and soil pH.

Sheets (22) reported that simazine-C^{14} was absorbed by the roots and that C^{14} was distributed throughout oat plants within 3 hours. The amount of C^{14} was reported to be dependent upon the rate of transpiration and solvent extracts of the treated tissues showed that measurable amounts of absorbed simazine was metabolized during a 24 hour exposure period. Ragab and McCollum (16) believe that production of $C^{14}O_2$ by corn and cucumber plants treated with simazine-C^{14} clearly demonstrates that both resistant and susceptible plants decompose simazine to non-toxic products. Roth was reported by Sheets (20) to have demonstrated that simazine tolerance in corn was due to a thermo-liable system. He found that only 3 per cent of the simazine could be recovered from normal expressed corn sap 100 hours after treatment but if the expressed sap was heated prior to treatment, 100 per cent of the simazine could be recovered.

Freed and his co-workers have been reported to feel that they can map many of the chemical reactions and structures of the intermediates of the oxidation of simazine and related triazines up through the cleavage of the triazine ring (2). By use of simazine and a related triazine, 2-chloro-4-ethylamino-isopropylamino-s-triazine (atrazine), labeled with Carbon-14, they found that expressed sap from corn tissues, a triazine tolerant plant, oxidized triazines to CO_2 and other unidentified compounds. Further tests by these workers demonstrated that at least one of the agents causing this

oxidation was thermo-liable and they have proposed that these were enzymes. They found the initial metabolic product of atrazine oxidation to be hydroxylated-atrazine and Freed speculates that this compound is often oxidized to a keto form. The keto-atrazine will then readily undergo hydrolyic cleavage of the triazine ring and the products oxidized.

Moreland et al. (13) reported that photosynthesis retarded in the leaves of several susceptible plants by the presence of simazine and studies indicate that the Hill reaction was the primary process affected. These workers also reported that simazine injury in barley seedlings, a susceptible plant, can be prevented by supplying an external source of glucose to the treated plants.

Simazine injury in susceptible plants occurs as chlorosis starting in the tips and margins of older leaves and progresses rapidly throughout the plant. Necrosis of the chlorotic tissues quickly follows in severely injured leaves (20). Using simazine-^{14} and radioautographs, Sheets (20) found that progressive accumulation of C^{14} within oat leaves was identical with the basipetal development of injury symptoms.

The role of microorganisms in decomposing simazine has been found by Ragab and McCollum (16) to be highly significant. During the first 91 hours following treatment, the rate of simazine decomposition quickly followed. The reduction was thought by the authors to be due to the toxic effects of high concentrations of simazine on the microorganisms present. Reid (17) reported that Corynebacteriacea soil bacteria are responsible for triazine decomposition.

Simazine action in soils has been studied by several workers, but a full explanation of its behavior has not been established. Sheets (20) and Upchurch (28) reported that organic matter is a major factor of simazine

phytotoxicity in soils. Scudder (18) reported that if high rates of simazine are mixed with the soil, the stand and vigor of sweet corn plantings 8 months after soil treatment are reduced. Holstrum et al. (10) and Bingham (4) found little movement of simazine in soils and that simazine phytotoxicity as demonstrated by plant bioassay was present only in the soil from the upper four inches when surface treatments were made.

Growth response of bioassay plants to simazine has been expressed in two ways; as a 50 per cent effective dose (ED_{50}) (19), and as a percentage growth reduction (GR_{50}) (27). The ED_{50} has been used where concentrations of the herbicide were of primary concern and a fresh weight measurement of aerial portion was used as the criteria for the determination. The GR rating proposed and used by Upchurch (27) designates the rate of a particular herbicide that reduces the treated plant's growth to a designated amount of the control plant's growth. The per cent reduction is expressed as a subscript and the type of measurement used for the determination is expressed in lower case letters and contained within parenthesis, i.e., GR_{50} (dsw) would mean a 50 per cent reduction in dry shoot weight. Neither of these rating systems have been accepted for general usage in bioassay studies with herbicides.

MATERIALS AND METHODS

The herbicides employed in this study were 2-chloro-4-ethylamino-6-diethylamino-s-triazine (trietazine), 2-chloro-4,6-bis(ethylamino)-s-triazine (simazine), dimethyl 2,3,5,6-tetrachloroterephthalate (dacthal), O-2,4-dichlorophenyl O-methyl isopropyl-phosphoramidothiate (zytron), N,N-di (n-propyl)-2,6-dinitroaniline (L-31864), and N,N-dimethyl-α - α -diphenyl-acetamide (diphenamid). All chemical formulations were prepared by the

manufacturers for use as water carried herbicides. Trietazine, simazine, dacthal and diphenamid were wettable powder formulations, while zytron and L-31864 were formulated as emulsifiable concentrates.

The soil used was an unnamed alluvial fine sand loam with a determined chemical analysis of 1.2 per cent organic matter content, pH value of 4.9, 100 pounds per acre available phosphorus, and 820 pounds per acre of exchangeable potassium. A mechanical analysis by the hydrometer method advanced by Bouyoucos (5) and using the United States Department of Agriculture soil particle classification divided the mineral portion of the soil into 4 per cent clay (below 0.002 mm), 35 per cent silt (0.05 to 0.002 mm), and 61 per cent sand (2.00 to 0.05 mm).

The concentrations of the herbicides determined as parts per million by weight (ppmw) of the molecular equivalent in 500 grams of air dry soil were trietazine at 2 and 4 ppmw, simazine at .5 and 1 ppmw, dacthal at 8 and 16 ppmw, zytron at 7.5 and 15 ppmw, L-31864 at 7.5 and 15 ppmw, and diphenamid at 5 and 10 ppmw. The oat (Avena sativa L., Kanota) was used as a bioassay plant to measure the level of phytotoxic soil residues.

Air dry soil samples of 500 grams each were placed in polyethylene bags in waxed cardboard containers. Stock solutions were prepared for each herbicide and an aliquot portion was applied to the surface of 30 soil samples for each respective treatment. Each treatment was replicated 5 times in each of 6 primary plantings. The initial primary planting of Kanota oats was made immediately prior to herbicide treatment, and the 5 additional primary plantings were made at 7 day intervals thereafter. For the remainder of this paper, the individual primary plantings will be referred to either by the number of days following herbicide application the bioassay plant was

was planted or by the planting's numerical position in their order of seeding, i.e., the primary planting made 21 days after herbicide application will be known as primary planting 4 or the primary planting made 21 days after treatment. Three repeat plantings were made to containers planted at earlier dates but from which the aerial portions had been removed for the weight measurements. The repeat plantings were made 42, 49, 63 days after herbicide application and will hereafter be known either by the number of days after soil treatment that the containers were seeded or by their numerical position in their order of planting, i.e., the repeat planting made 49 days after treatment will be known as either repeat planting 3 or the planting made 49 days after treatment. Fifteen oat seeds were planted at a depth of one-fourth inch in each container on their respective planting dates. After the initial primary planting and herbicide application, the moisture level of all containers was brought up to field capacity for the soil, and the containers were placed in a greenhouse on an open bench. Night temperatures ranging from 50 to 70° F and day temperatures ranging from 65 to 80° F were maintained. Moisture levels in both planted and unplanted containers was maintained between field capacity and 40 per cent of field capacity.

Visual observations were made daily throughout the 30 day growing period. At the end of the period, counts of plants showing apparent tolerance to the chemical residues, and measurements of the fresh and dry weights of the aerial portions of the plants were made. A double beam Harvard trip scale balance considered accurate to 0.05 grams was used for all weight measurements. Descriptions of anatomical modifications by the oat in response to herbicidal residues in the soil were based upon the Avena seedling anatomy

described by Hector (9) and by Boyd and Avery (6). All statistical analyses were calculated through procedures outlined by Snedecor (24).

RESULTS

Visual Observations

Visual observations were made daily throughout the 30 day growing period, and abnormal growth modifications and reactions of the oat plants were noted. The plants seeded at each respective planting date were compared with those in the control containers. Normal germination and emergence of the oat seedlings occurred 4 to 5 days after seeding in all containers but those treated with diphenamid in which only a few seedlings emerged. The oat seedlings in the control containers had grown to a height of 20 to 25 cm by the end of the 30 day test period.

The induced growth modifications and reactions of the bioassay plants will be discussed separately for each of the herbicides employed in this study.

Trietazine. Injury to oat seedlings from toxic residues of trietazine occurred after the oat seedlings had reached a height of 10 to 15 cm and were in the third week of growth. Prior to the initial observed injury, the seedling oats appeared to grow normally. Initial injury appeared as chlorosis of the oldest leaf tip. Later, all the leaves of the injured plants became chlorotic at the tip and chlorosis rapidly progressed throughout the plant in a basipetal pattern. Typical injury symptoms are illustrated in Figure 1.

Necrosis of the tissues quickly followed chlorosis and death of the severely injured plants usually occurred within 10 days of the first observed chlorotic tissues. Injury symptoms first appeared on plants receiving

Figure 1. Typical injury symptoms of Kanota oat plants resulting from toxic soil residues of simazine and trietazine applied at rates of 1 and .5 ppmw, and 2 and 4 ppmw, respectively. Picture was taken 30 days after planting.

trietazine regardless of rates, on the sixteenth day after seeding in the initial primary planting made at time of herbicide application.

Simazine. Foliar symptoms in the oat as result of toxic soil residues of simazine were identical in appearance to those induced by trietazine. Typical symptoms are illustrated in Figure 1. The chief difference in the injury symptoms of simazine and trietazine was the time of initial appearance of the observed injury symptoms in plants growing in the first primary planting. The first symptoms of injury appeared in these plants about 5 days later in containers treated with simazine than in similar containers treated with trietazine.

Dacthal. Phytotoxic soil residues of dacthal did not affect the emergence of the Kanota oat seedlings, but they caused seedling development to be retarded and modified. Emergence of the first true leaf was delayed, or in early initial plantings, true leaves did not emerge from the sheath before the plant died. Elongation of the true leaf blade was much slower in injured plants and the resultant leaf blade was shorter, wider and thicker than normal leaves of the control plants. These malformed leaves also had an abnormal blunt tip. Typical injury symptoms are illustrated in Figure 2. Plants apparently tolerant to dacthal soil residues were delayed in initial true leaf elongation for about 3 days, but their growth during the remainder of the 30 day period was apparently normal. Severely injured plants grew to a total height of less than 3 cm, and only the first true leaf emerged.

In addition to anatomical growth modifications, plants injured by soil residues of dacthal developed irregular brown spots in the leaf blade. These spots began occurring the second week after expansion of the true leaf and they were very irregular in shape, size and location. The rate of spot

Figure 2. Typical injury symptoms of Kanota oat plants resulting from toxic soil residues of dacthal applied at 16 ppmw and zytron applied at 15 ppmw.

Picture was taken 30 days after planting.

expansion varied with the date of planting and the most rapid expansion occurred in the earlier primary plantings. The characteristic spots were present in all the injured plants prior to their death and the rate of spot expansion appeared to be a direct factor in the time of plant death. All injured plants died within the 30 day period in treated containers of the first 4 primary plantings, but many of the injured plants in later plantings were still alive at the end of the 30 day period.

Zytron. Severe injury symptoms resulting from phytotoxic soil residues of zytron were essentially the same as those described for dacthal except for the time of initial appearance and rate of spot expansion. The occurrence and development of the characteristic brown spots and the anatomical malformations were more severe in plants of containers treated with zytron than those growing in dacthal treated containers of the first two primary plantings. Oat plants growing in zytron treated containers seeded on or after the fourteenth day following treatment, showed progressively less injury symptoms from the toxic residues.

Severely injured oat plants had a marked swelling about 3 times the diameter of the normal stem immediately below the crown node in addition to the observed foliar symptoms. Detailed studies of these swellings were not made, but it appeared the area of swelling was the second internode located between the coleoptile node and the crown node. Severely injured plants growing in containers seeded at the date of treatment died during the third week after planting, and most of the severely injured plants in the second primary planting died during the fourth week.

Some of the oat plants in these containers developed what were considered to be partial injury symptoms of two general types. The first type

of partial injury was similar to what has been described previously as a severe injury, except the swelling did not develop and the true leaf blade grew to a height of about 9 cm. Death of these plants occurred if the previously described brown spots developed; but if after a period of about one week no spots developed, additional true leaves were produced and the plants continued apparent normal growth. Dwarfing was the second type of partial injury symptom noted. Plants of this type did not develop the characteristic spots, and except for reduction in size, appeared to tolerate the chemical.

L-31864. After normal emergence from the soil, most of the oat seedlings in containers treated with L-31864 ceased to grow or develop, and all but a few apparently tolerant to the chemical residues were dead within 10 days of emergence. No malformed or abnormal anatomical structures were formed. Death of the plant was the typical occurrence in containers of the first two primary plantings treated at both rates and in containers of the third primary planting treated at the 15 ppmw rate.

Oat plants partially injured by phytotoxic residues of this chemical grew to a height of only 8 cm, but were otherwise normally developed. Oat plants seeded 35 days after herbicide application or in the repeat plantings were only partially injured or had apparent tolerance to the chemical residues.

Diphenamid. Plant growth in containers treated with diphenamid was limited to a few containers in the first two primary plantings and the repeat plantings. This growth consisted of a few plants apparently tolerant to the chemical residues and some seedlings whose coleoptile shoots emerged, but whose true leaves did not emerge before death of the plant. All of these seedlings died during the week following emergence, except for those apparently tolerant to the residues.

Plant Counts

Plant counts were made at the end of the 30 day growing period to determine the number of plants having each type of injury symptom and the number of plants showing apparent tolerance to the herbicide residues. Only the counts of plants apparently tolerant to the chemical residues are reported in this paper. All plant counts from treated containers were compared to 14, the mean number of plants growing in the control containers.

Statistical analyses of the plant counts from all of the treatments but diphenamid at 5 ppmw and 10 ppmw, are reported in Table 3 for the primary plantings and Table 4 for the repeat plantings. An LSD value was calculated at the 5 per cent probability level for each group of plantings and all comparisons between treatments and plantings were made using the LSD values and the mean plant counts presented in Tables 1 and 2. Tables 9 through 17 located in the appendix contain detailed plant count data for each of the respective plantings. The high variation between plant counts within the same treatment and planting can be seen in the tables. No transformation could be found to reduce internal sample variance within limits necessary for a homogeneous population; therefore, in making the comparisons reported in this paper, analyses were performed which require that homogeneity be assumed.

All comparisons of the plant count means from different treatments and plantings will be discussed for each herbicide separately.

Trietazine. The number of plants in containers treated with 2 ppmw of trietazine and having apparent tolerance to the soil residues, increased progressively with each successive primary planting from the first to the last.

Table 1. The mean number of plants 30 days after seeding, showing apparent tolerance to herbicide residues in the containers of each primary planting.

Chemicals	(ppmw)	Primary plantings					
		1	2	3	4	5	6
Control		14.0	14.0	14.0	14.0	14.0	14.0
Trietazine	2	1.6	5.6	5.6	7.8	9.6	11.0
	4	0.4	1.2	2.2	2.4	2.8	4.2
Simazine	.5	4.0	4.6	6.0	2.4	1.8	8.2
	1	0.4	1.6	0.6	0.6	0.4	0.6
Dacthal	8	1.0	1.6	0.8	1.4	1.0	4.0
	16	0.8	1.0	0.6	1.2	1.0	2.8
Zytron	7.5	1.6	2.4	3.0	5.0	3.6	10.0
	15	0.8	1.2	2.2	2.2	1.4	6.6
L-31864	7.5	0.4	2.2	2.2	1.8	0.8	5.0
	15	0.6	0.6	0.4	0.6	0.6	2.8

$LSD_{.05}$ = 1.63 (Valid comparisons can be made between treatments same planting and between plantings same treatment).

Table 2. The mean number of plants 30 days after seeding, showing apparent tolerance to herbicide residues in containers of each repeat planting.

Chemicals	(ppmw)	Repeat plantings 1	2	3
Control		14.0	14.0	14.0
Tristazine	2	11.2	9.2	14.0
	4	1.6	4.2	11.8
Simazine	.5	5.2	9.4	12.0
	1	0.6	0.4	2.2
Dacthal	8	5.2	12.0	11.4
	16	6.6	11.2	12.2
Zytron	7.5	12.8	12.8	13.8
	15	8.4	11.8	13.4
L-31864	7.5	7.4	9.2	11.8
	15	7.6	6.0	10.4

$LSD_{.05}$ = 2.10 (Valid comparisons can be made between treatments same planting and between plantings same treatment).

Table 3. Analysis of variance of the plant counts[1] of the six primary plantings.

Factors	Degrees of freedom	Mean squares	F
Total	299		
Treatment	9	115.01	66.48***
Plantings	5	108.73	62.85***
Replications	4	3.71	2.14*
Treatment × Planting Interaction	45	8.87	5.13***
Error	236	1.73	

Table 4. Analysis of variance of the plant counts[1] of the three repeat plantings.

Factors	Degrees of freedom	Mean squares	F
Total	149		
Treatments	9	137.78	47.51***
Plantings	2	271.50	93.62***
Replications	4	4.25	1.46
Treatment × Planting Interaction	18	16.89	5.82***
Error	116	2.90	

[1]The plant counts were made 30 days after planting.
***Significant at the .5 per cent probability level.
*Significant at the 10 per cent probability level.

All mean plant counts of the primary planting from containers receiving applications of 2 ppmw of trietazine were significantly less than those of the controls. The following significant differences expressed in terms of plant counts were found between consecutive primary plantings; 2 was greater than 1; 4 was greater than 3; and, 5 was greater than 4. Direct comparisons between plant count means of primary plantings and repeat plantings were not made due to the variation of the control containers of the two planting groups. The factors believed to cause these variations are discussed in a later section.

Mean plant counts of containers treated with 2 ppmw of trietazine in repeat plantings 1 and 2 were found to be significantly less than those of repeat planting 3. Containers treated with 4 ppmw of trietazine in repeat planting 1 had significantly fewer plants apparently tolerant to the chemical residues than did similar containers in repeat planting 2; and there were significantly fewer plants of this type in containers treated with 4 ppmw of trietazine in repeat planting 2 than in similar containers in repeat planting 3.

Mean plant counts of containers treated with 4 ppmw of trietazine did not differ significantly between consecutive primary plantings. The mean plant counts of containers treated with 2 ppmw of trietazine were significantly greater than from containers treated with 4 ppmw of trietazine in every planting, but primary planting 1.

Simazine. All mean plant counts of containers receiving applications of simazine at either .5 ppmw or 1 ppmw were significantly less than the mean plant counts for the controls in every planting, except the mean plant count of containers treated at the .5 ppmw rate and seeded in the third repeat

planting. Mean plant count of containers treated with .5 ppmv of simazine in primary planting 3 was significantly greater than containers of the identical treatment in primary planting 4 and the mean plant count of containers treated with .5 ppmv of simazine in primary planting 6 was significantly greater than the mean plant count of containers treated with the same treatment in primary planting 5. Mean plant counts of containers treated with .5 ppmv of simazine and seeded on each of the repeat planting dates were significantly greater for each consecutively later planting, from the first to the third. All of the mean plant counts of containers treated with .5 ppmv of simazine were significantly greater than those in the same planting but receiving the 1 ppmv application rate of simazine, except for primary planting 5 where the mean plant counts did not differ significantly.

Dacthal. All the mean plant counts for containers treated with 8 ppmv and 16 ppmv of dacthal were significantly less than the control mean plant counts, except for containers in repeat planting 2 that were treated with 8 ppmv of dacthal and containers in repeat planting 3 that were treated with 16 ppmv of dacthal. Containers of primary planting 6 receiving dacthal treatments had significantly greater numbers of plants apparently tolerant to the remaining chemical residues than containers treated with dacthal in primary planting 5 regardless of the treatment rate. Also, there were significantly greater numbers of plants apparently tolerant to herbicide residues in containers treated with 8 ppmv of dacthal than those treated with 16 ppmv of dacthal in every planting but repeat planting 3.

Zytron. The mean plant counts of containers treated with 7.5 ppmv of zytron were significantly greater than those treated with 15 ppmv of zytron in primary plantings 4, 5, and 6 and in repeat planting 1. All the mean

plant counts of containers treated with 7.5 ppmv or 15 ppmv of sytron were significantly less than those of the control containers in all the plantings except repeat planting 3 which was not significantly different at either rate.

The mean plant counts of containers treated with 7.5 ppmv of sytron and seeded on consecutive planting dates were significantly different as follows: primary planting 4 was greater than primary planting 3; and, primary planting 6 was greater than primary planting 5. The mean plant counts of containers treated with 15 ppmv of sytron and seeded on consecutive planting dates were significantly different as follows: primary planting 6 was greater than primary planting 5; and, repeat planting 3 was greater than repeat planting 2.

L-31864. The mean number of plants apparently tolerant to herbicidal residues in all of the containers treated with 7.5 ppmv and 15 ppmv of L-31864 were significantly less than the mean number of plants in the control containers. The mean plant counts of containers treated with 7.5 ppmv of L-31864 were significantly greater than the mean plant counts of containers treated with 15 ppmv of L-31864 in primary plantings 2 and 3, and repeat planting 2. Significant differences were found between the mean number of plants apparently tolerant to the chemical residues in containers treated with 7.5 ppmv of L-31864 and seeded in consecutive plantings as follows: primary planting 2 was greater than primary planting 1; primary planting 6 was greater than primary planting 5; and, repeat planting 3 was greater than repeat planting 2. The mean plant counts of primary planting 6 were greater than those of repeat planting 2 in containers treated with 15 ppmv of L-31864.

Diphenamid. Comparisons of the number of plants having apparent tolerance to the herbicidal residues in containers treated with diphenamid at 5 ppmv and 10 ppmv were not made because oat plants apparently tolerant

to the soil residues of this herbicide were present in only 6 of the 90 containers seeded with the bioassay plant during the experimental period.

Fresh and Dry Plant Weight Measurements

The aerial portions of the Kanota oat plants were removed from each container at the end of the 30 day growing period and placed in a small pre-weighed seamless tin canister. Each canister and the plant material enclosed within it were accurately weighed, and the fresh plant weight for the aerial portion of the oat plants in each container was calculated. The canisters with the plant material were then placed open in a mechanical convection oven, and the plant material dried at a temperature of 105° C for 15 hours, the time necessary to dry all of the plant material samples to a constant weight. The dried plant material was very brittle, but still retained its natural color and structure. After being allowed to cool, the canisters were accurately weighed and the dry plant weight of the plant material from each of the containers was calculated.

All plant weight measurements were converted to a percentage of the mean plant weight measurements for the control containers for each type of measurement in each respective planting. This was done in order to allow accurate comparisons of the plant weight measurements for the aerial portions of the bioassay plants in each container treated with one of the various treatments of a herbicide and seeded on one of the various planting dates. The unconverted fresh plant weight measurements are found in Tables 18 through 23, and Tables 24 through 29 contain the unconverted dry plant weight measurements. The converted fresh plant weight measurements are listed in Tables 30 through

35, and the converted dry plant weight measurements are listed in Tables 36 through 41. All of these detailed tables are located in the appendix.

The variation between the plant weight measurements from containers of the same treatment and planting is shown in the tables, and because of this high within sample variation, homogeneity of population variance was doubtful but was assumed for the statistical analyses. The analysis of variance for the converted fresh plant weight measurements is located in Table 7 and the analysis of variance for the dry plant weight measurements is in Table 8. All comparisons of the plant weight measurements were made using the means of the converted measurements and the LSD values calculated with a 5 per cent probability level. These mean plant weight measurements and the LSD value are found in Table 5 for the fresh plant weight measurements and in Table 6 for the dry plant weight measurements.

Plant weight measurements were taken for the plant material samples from containers of the 6 primary plantings only, since oat plants in the control containers of the repeat plantings were uneven in growth and some were semi-dwarfed. Suggested reasons for the abnormal growth of the oat plants in the control containers of the repeat plantings are given in the discussion section. The fresh and dry plant weight measurements of the different treatments and plantings will be discussed for each herbicide separately. Only comparisons between the mean weight measurements of different treatment rates for the same herbicide, of consecutive plantings for the same treatment, and of treatments with the control will be reported.

Trietasine. All of the mean plant weight measurements of containers treated with trietasine at 2 and 4 ppmw were significantly smaller than the mean plant weight measurements of the control containers except the mean fresh

Table 5. Mean values for fresh plant weight measurements[1].

Chemicals	(ppmw)	Primary plantings 1	2	3	4	5	6
Control		.998	.996	.996	.996	.998	1.004
Trietazine	2	.098	.300	.570	.354	.850	.804
	4	.112	.144	.288	.186	.404	.172
Simazine	.5	.178	.178	.500	.128	.230	.410
	1	.066	.112	.080	.078	.038	.102
Dacthal	8	.152	.182	.096	.098	.222	.390
	16	.116	.150	.120	.094	.136	.282
Zytron	7.5	.220	.180	.492	.400	.490	.864
	15	.068	.208	.324	.212	.320	.778
L-31864	7.5	.072	.332	.390	.158	.132	.482
	15	.112	.062	.108	.058	.198	.374

$LSD_{.05}$ = 0.155 (Valid for comparisons between treatments same planting and between plantings same treatment).

[1]The measurements were made 30 days after planting and are expressed as the per cent of the mean for the control containers in each respective planting.

Table 6. Mean values for dry plant weight measurements[1].

Chemicals	(ppmw)	Primary plantings 1	2	3	4	5	6
Control		1.000	1.002	1.000	.998	.998	1.000
Trietazine	2	.186	.354	.360	.360	.694	.440
	4	.118	.246	.260	.108	.376	.380
Simazine	.5	.186	.190	.420	.090	.238	.702
	1	.072	.136	.100	.036	.044	.200
Dacthal	8	.254	.326	.180	.234	.306	.720
	16	.230	.300	.220	.162	.218	.600
Zytron	7.5	.510	.488	.720	.634	.824	.980
	15	.232	.326	.480	.306	.584	.840
L-31864	7.5	.208	.354	.450	.270	.282	.860
	15	.234	.082	.220	.126	.370	.620

$LSD_{.05}$ = 0.201 (Valid for comparisons between treatments same planting and between plantings same treatment).

[1]The measurements were made 30 days after planting and are expressed as the per cent of the mean for the control containers in each respective planting.

Table 7. Analysis of variance for the fresh plant weight measurements[1].

Factors	Degrees of freedom	Mean squares	F
Total	329		
Treatments	10	1.9755	126.68***
Plantings	5	.7124	45.62***
Replications	4	.0501	3.21**
Treatment × Planting Interaction	50	.0769	4.29***
Error	260	.0156	

Table 8. Analysis of variance for the dry plant weight measurements[1].

Factors	Degrees of freedom	Mean squares	F
Total	329		
Treatments	10	1.8104	46.18***
Plantings	5	1.0685	27.26***
Replications	4	.0426	1.09
Treatment × Planting Interaction	50	.0635	1.62***
Error	260	.0392	

[1]The measurements were made 30 days after planting and are expressed as the per cent of the mean for the control containers in each respective planting.

***Significant at the .5 per cent probability level.

**Significant at the 5 per cent probability level.

plant weight measurement for containers treated with 2 ppmw of trietazine and seeded for primary planting 5, which was not significantly different from that of the control containers. The mean fresh plant weight measurement of containers treated with trietazine were significantly different in the following consecutive plantings: primary planting 3 was larger than primary plantings 2 and 4, and primary planting 5 was larger than primary planting 4 at 2 ppmw treatment rate; and, primary planting 5 was larger than primary plantings 4 and 6 at the 4 ppmw treatment rate. The mean fresh plant weight measurements of containers treated with 2 ppmw of trietazine were significantly larger than those of containers treated with 4 ppmw of trietazine in every primary planting except for primary planting 1.

The mean dry plant weight measurements of containers treated with trietazine at rates of 2 and 4 ppmw were significantly different as follows: primary planting 5 was larger than primary plantings 4 and 6 at the 2 ppmw rate; and primary planting 5 was larger than planting 4 at the 4 ppmw rate. The mean dry plant weight measurements of containers treated with 2 ppmw of trietazine were significantly larger than those of containers treated with 4 ppmw of trietazine in primary plantings 4 and 5.

Simazine. The means of both fresh plant weight measurements and dry plant weight measurements from containers treated with simazine at .5 ppmw were significantly different between consecutive plantings as follows: primary planting 3 was larger than primary plantings 2 and 4; and, primary planting 6 was larger than primary planting 5. All of the weight measurements of the aerial portions of oat plants growing in containers treated with simazine at .5 and 1 ppmw were significantly smaller than those of oat plants growing in the control containers.

The mean fresh plant weight measurements from containers treated with .5 ppmw of simazine were significantly larger than those from containers treated with 1 ppmw of simazine in primary plantings 3, 5, and 6. The mean dry plant weight measurements from containers treated with .5 ppmw of simazine were significantly larger than those in containers treated with 1 ppmw of simazine in primary plantings 3 and 6.

Dacthal. The mean fresh and dry plant weight measurements of the aerial portions of oat plants growing in the control containers were larger than those of the oat plants growing in the containers treated with dacthal at 8 and 16 ppmw. The mean fresh plant weight measurements from containers treated with dacthal at 8 and 16 ppmw were significantly larger in primary planting 6 than those in primary planting 5. The mean dry plant weight measurements of containers treated with dacthal at 16 ppmw were significantly larger than in primary planting 6 than those in primary planting 5.

Zytron. The mean fresh and dry plant weight measurements from containers treated with zytron at 7.5 and 15 ppmw of zytron were significantly smaller than those from the control containers in every primary planting except the following mean plant weight measurements that were not significantly different from those of the controls: the mean fresh plant weight measurement of containers treated with zytron at 7.5 in primary planting 6; and, the mean dry plant weight measurements of primary plantings 5 and 6 from containers treated with 7.5 ppmw of zytron, and of primary planting 6 from containers treated with 15 ppmw of zytron.

The following significant differences were found between the mean fresh plant weight measurements of containers treated with zytron and seeded in consecutive primary plantings: primary planting 3 was larger than primary

planting 2, and primary planting 6 was larger than primary planting 5 at the 7.5 ppmw treatment rate; and, primary planting 6 was greater than primary planting 5 at the 15 ppmw treatment rate. The mean dry plant weight measurements from containers treated with zytron and seeded in consecutive primary plantings were significantly different as follows: primary planting 3 was larger than primary planting 2 at the 7.5 ppmw treatment rate; and, primary planting 5 was greater than 4 and smaller than 6 at the 15 ppmw treatment rate.

The mean fresh plant weight measurements of containers treated with 7.5 ppmw of zytron were significantly greater than those treated with 15 ppmw of zytron in primary planting 3, while all such comparisons of dry plant weight measurements were significantly greater in every planting except primary plantings 2 and 6.

L-31864. The mean fresh plant weight measurements and dry plant weight measurements from control containers were significantly larger than those from the containers treated with L-31864 at 7.5 and 15 ppmw in every primary planting excepting primary planting 6 where the mean dry plant weight measurement from containers treated with L-31864 at 7.5 ppmw were not significantly different from that of the control containers. The mean fresh plant weight measurements from containers treated with L-31864 and seeded in consecutive plantings were significantly different as follows: primary planting 4 was larger than primary planting 3, and primary planting 6 was larger than primary planting 5 at the 7.5 ppmw treatment rate; and, primary planting 6 was larger than primary planting 5 at the 15 ppmw treatment rate. The mean dry plant weight measurements of containers treated with L-31864 and seeded in consecutive plantings were significantly different as follows: primary planting 6 was

greater than primary planting 5 of the 7.5 ppmw treatment; and, primary planting 5 was larger than primary planting 4 and was smaller than primary planting 6.

The mean fresh plant weight measurements and dry plant weight measurements of containers treated with L-31864 of 7.5 were significantly larger than those of containers treated with L-31864 at 15 ppmw in primary plantings 2 and 3.

Diphenamid. The weight measurements of aerial portions of the plants were not reported compared, or included in the statistical analyses, since only 6 of the 90 containers seeded during the progress of the experiment contained measurable plant growth.

DISCUSSION

Reduction of the aerial portions of a bioassay plant as indicated by fresh plant or dry plant weight measurements has been the criteria used to determine the toxic life of herbicides in the soil for most published papers. While such measurements are factual and unbiased, they may not in some cases present a true measurement of the phytotoxicity of the herbicidal residues on the test plant. It was difficult in this experiment to critically compare herbicides, such as trietazine and zytron, which caused completely different growth modifications and reactions in the bioassay plants. The herbicidal action of trietazine appeared to be exerted only after the seedling plant was established and considerable growth had been made. Early recognizable differences between the growth of plants in containers with trietazine treated soil and with untreated soil were small. However, the herbicidal action of zytron seemingly happened as the seedling plant was emerging and if the

seedling became established, the herbicide residues apparently caused no serious injury. Growth differences between the bioassay plants growing in containers with sytron treated soil and with untreated soil were greatest at the beginning of the growth period; these differences decreased as growth accelerated in those plants apparently tolerant to the herbicides.

The counts of plants apparently tolerant to the herbicide residues were considered the most accurate of the measurements used to determine the levels of phytotoxic residues in the soils. This measurement allowed both a quantitative and a qualitative evaluation of the injury of the bioassay plants by the herbicide residues. The chief fault of this measurement was that it was not accurate in measuring the reduction in quantity of test plant tissue caused by some groups of herbicidal chemicals.

Herbicides, such as simazine and trietazine, appeared dependent upon the establishment of the seedling plant and the resulting water transport, for their absorption and translocation within the susceptible plant. Susceptible plants appeared subject to injury symptoms from these chemicals over a relatively long period of time and though they appeared to tolerate the herbicide residues, if placed under nutrient or moisture stress, severe injury symptoms developed. It was felt that the herbicidal chemicals were present in the plants at the same concentrations before and after the injury symptoms occurred in the apparently tolerant plants, but the stress conditions caused a decrease in the synthesis of sugars within the plant. Such reductions in the quantity of test plant tissue of the injured plant were masked by apparently normal vegetative growth, and were measurable only in part by the dry plant weight measurements.

Each of these groups of pre-emergence herbicides may require different experimental designs to allow accurate measurement of their herbicidal action on the bioassay plants. They seemed compatible to the same experimental designs for only general measurements and comparisons.

SUMMARY AND CONCLUSIONS

The phytotoxic soil residues of 8 pre-emergence herbicides at two rates each were measured by the growth of the aerial portions of a bioassay plant, the Kanota oat. Each of the herbicide treatments was applied to 30 containers holding 500 gram samples of an alluvial fine sandy loam soil. Plantings of the bioassay plants were made at weekly intervals starting with the date of herbicide application. Upon completion of the treatment application, and the seeding of the primary planting of the bioassay plant, the experimental containers were placed on an open bench in a greenhouse maintained at favorable light conditions and growing temperatures. The soil of the containers was maintained at moisture levels considered favorable for plant and microorganism growth. Visual observations of the oat growth were made daily, and at the end of the 30 day growing period, plant counts and weight measurements of the aerial portion of the bioassay plants were made.

As a result of the research reported, the following conclusions were reached:

Pre-emergence herbicides employed in this study can be classified into 3 groups based on the time of herbicidal action: (a) chemicals that kill the weed seed or seedling prior to the emergence from the soil; (b) chemicals that retard the growth and development of the emerged seedling but kill prior to its establishment; and, (c) chemicals that kill the seedlings after they

are established as a result of the toxic action of the accumulated herbicidal chemical in the plant tissues.

The relative life spans of the phytotoxic soil residues for the herbicide treatments employed in this experiment were as follows:

a. zytron treatment at 7.5 ppmw had a phytotoxic life of about 40 days;

b. trietazine treatments at 2 ppmw, dacthal treatments at 8 and 16 ppmw, zytron treatments at 15 ppmw, and L-31864 treatments at 7.5 ppmw had a phytotoxic life of about 60 days;

c. trietazine treatments at 4 ppmw, simazine treatments at .5 and 1 ppmw, L-31864 treatments at 15 ppmw, and diphenamid treatments at 5 and 10 ppmw showed phytotoxic residues in excess of 60 days.

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APPENDIX

Table 9. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted at the time of treatment.

Chemicals (ppmw)		Replications					Mean
		1	2	3	4	5	
Tricazine	2	1	2	1	2	2	1.6
	4	1	1	0	0	0	0.4
Simazine	.5	7	5	4	1	3	4.0
	1	0	1	1	0	0	0.4
Dacthal	8	0	1	3	1	0	1.0
	16	0	1	2	1	0	0.8
Zytron	7.5	1	1	3	1	2	1.6
	15	0	1	0	2	1	0.8
L-31864	7.5	0	1	0	0	1	0.4
	15	2	0	0	0	1	0.6
Diphenamid	5	2	1	1	0	1	1.0
	10	0	0	0	0	1	0.2

Table 10. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 7 days after treatment.

Chemicals (ppmw)		Replications					Mean
		1	2	3	4	5	
Tricazine	2	4	8	5	5	6	5.6
	4	0	2	1	1	2	1.2
Simazine	.5	3	4	8	5	3	4.6
	1	0	0	5	0	3	1.6
Dacthal	8	1	2	2	2	1	1.6
	16	0	1	1	2	1	1.0
Zytron	7.5	3	3	3	2	1	2.4
	15	0	1	1	3	1	1.2
L-31864	7.5	1	2	1	3	4	2.2
	15	0	1	0	0	2	0.6
Diphenamid	5	0	0	0	0	0	0.0
	10	0	0	0	0	0	0.0

[1]The plant counts were made 30 days after seeding.

Table 11. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 14 days after treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Tricazine	2	5	6	4	7	6	5.6
	4	0	3	1	2	5	2.2
Simazine	.5	6	3	4	9	8	6.0
	1	1	0	0	1	1	0.6
Dacthal	8	1	1	1	1	0	0.8
	16	1	0	1	1	0	0.6
Zytron	7.5	3	3	3	2	4	3.0
	15	0	6	4	0	1	2.2
L-31864	7.5	3	2	2	0	4	2.2
	15	0	0	1	0	1	0.4
Diphenamid	5	0	0	0	0	0	0.0
	10	0	0	0	0	0	0.0

Table 12. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 21 days after treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Tricazine	2	9	9	6	7	8	7.8
	4	4	2	2	2	2	2.4
Simazine	.5	3	2	4	1	2	2.4
	1	1	1	1	0	0	0.6
Dacthal	8	1	2	0	1	3	1.4
	16	2	0	3	1	0	1.2
Zytron	7.5	3	7	8	5	2	5.0
	15	4	1	0	3	3	2.2
L-31864	7.5	1	1	1	2	4	1.8
	15	1	0	1	1	0	0.6
Diphenamid	5	0	0	0	0	0	0.0
	10	0	0	0	0	0	0.0

[1]The plant counts were made 30 days after seeding.

Table 13. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 28 days after treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Tricazine	2	9	11	10	9	9	9.6
	4	4	2	3	3	2	2.8
Simazine	.5	1	3	2	0	3	1.8
	1	0	0	2	0	0	0.4
Dacthal	8	0	0	2	1	2	1.0
	16	1	3	0	0	1	1.0
Zytron	7.5	3	2	5	4	4	3.6
	15	1	4	1	0	1	1.4
L-31864	7.5	0	0	3	1	0	0.8
	15	2	0	1	0	0	0.6
Diphenamid	5	0	0	0	0	0	0.0
	10	0	0	0	0	0	0.0

Table 14. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 35 days after treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Tricazine	2	10	11	11	10	13	11.0
	4	3	6	5	3	4	4.2
Simazine	.5	8	10	9	5	9	8.2
	1	0	0	2	1	0	0.6
Dacthal	8	2	2	5	5	6	4.0
	16	4	3	2	3	2	2.8
Zytron	7.5	7	11	10	11	11	10.0
	15	6	6	7	7	7	6.6
L-31864	7.5	6	9	4	4	2	5.0
	15	3	2	4	4	1	2.8
Diphenamid	5	0	0	0	0	0	0.0
	10	0	0	0	0	0	0.0

[1]The plant counts were made 30 days after seeding.

Table 15. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 42 days after treatment.

Chemicals (ppmw)	Replications 1	2	3	4	5	Mean
Tricazine 2	14	9	11	11	12	11.2
4	3	2	1	0	2	1.6
Simazine .5	7	9	2	2	6	5.2
1	1	1	0	1	0	0.6
Dacthal 8	8	5	4	4	5	5.2
16	4	7	7	6	9	6.6
Zytron 7.5	14	14	10	14	12	12.8
15	7	10	6	9	10	8.4
L-31864 7.5	5	9	8	6	9	7.4
15	8	6	7	8	9	7.6
Diphenamid 5	0	0	0	1	0	0.2
10	0	0	0	0	0	0.0

Table 16. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 49 days after treatment.

Chemicals (ppmw)	Replications 1	2	3	4	5	Mean
Tricazine 2	8	10	9	11	8	9.2
4	2	5	4	6	4	4.2
Simazine .5	9	7	11	7	13	9.4
1	0	1	0	1	0	0.4
Dacthal 8	9	12	14	12	13	12.0
16	8	12	11	13	12	11.2
Zytron 7.5	14	14	13	11	12	12.8
15	10	14	11	11	13	11.8
L-31864 7.5	10	10	9	9	8	9.2
15	8	11	4	3	4	6.0
Diphenamid 5	0	0	0	0	1	0.2
10	0	0	0	0	0	0.0

[1]The plant counts were made 30 days after seeding.

Table 17. The number[1] of Kanota oat plants showing apparent tolerance to herbicide residues in the soil of containers planted 63 days after treatment.

Chemicals	(ppmw)	Replications					Mean
		1	2	3	4	5	
Trietazine	2	14	14	14	14	14	14.0
	4	14	12	13	11	9	11.8
Simazine	.5	12	14	13	11	10	12.0
	1	0	1	0	4	6	2.2
Dacthal	8	10	11	13	14	9	11.4
	16	12	11	14	11	13	12.2
Zytron	7.5	14	13	14	14	14	13.8
	15	13	14	13	14	13	13.4
L-31864	7.5	12	14	12	9	12	11.8
	15	12	12	9	11	8	10.4
Diphenamid	5	0	0	0	0	0	0.0
	10	0	0	0	0	0	0.0

[1]The plant counts were made 30 days after seeding.

Table 18. Fresh plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted at the time of herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		2.35	2.10	2.65	2.20	2.00	2.26
Tricazine	2	.15	.45	.50	.25	.25	0.32
	4	.40	.50	.15	.15	.10	0.26
Simazine	.5	.65	.70	.30	.10	.30	0.41
	1	.10	.20	.30	.10	.10	0.16
Dacthal	8	.05	.30	.90	.40	.10	0.35
	16	.05	.30	.55	.25	.20	0.26
Zytron	7.5	.50	.25	.90	.30	.55	0.50
	15	.05	.25	.00	.30	.20	0.16
L-31864	7.5	.00	.30	.10	.05	.40	0.17
	15	.75	.10	.05	.10	.30	0.26

Table 19. Fresh plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 7 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		2.40	1.95	2.35	2.30	2.20	2.24
Tricazine	2	.85	.90	.50	.60	.55	0.68
	4	.20	.45	.45	.25	.30	0.33
Simazine	.5	.40	.30	.65	.60	.05	0.40
	1	.10	.10	.50	.10	.50	0.26
Dacthal	8	.20	.20	.70	.70	.30	0.42
	16	.05	.30	.60	.30	.45	0.34
Zytron	7.5	.70	.25	.60	.30	.20	0.41
	15	.20	.80	.75	.30	.35	0.48
L-31864	7.5	.05	1.35	.20	.70	1.45	0.75
	15	.00	.10	.00	.05	.55	0.14

[1]The measurements were made 30 days after seeding.

Table 20. Fresh plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 14 days after herbicide treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Control		2.65	2.00	2.75	2.20	2.70	2.46
Tricazine	2	1.00	1.40	1.55	1.45	1.60	1.40
	4	.10	1.00	.80	.25	1.40	0.71
Simazine	.5	1.55	1.00	.50	1.25	1.85	1.23
	1	.30	.00	.00	.30	.40	0.20
Dacthal	8	.20	.40	.20	.35	.05	0.24
	16	.30	.20	.40	.35	.25	0.30
Zytron	7.5	1.30	1.20	1.25	1.20	1.15	1.22
	15	.30	1.85	1.15	.25	.45	0.80
L-31864	7.5	1.20	1.00	.85	.25	1.65	0.99
	15	.20	.15	.35	.25	.40	0.27

Table 21. Fresh plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 21 days after herbicide treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Control		2.50	2.70	2.95	2.20	2.75	2.62
Tricazine	2	.85	1.45	.75	.35	1.30	0.94
	4	.50	1.00	.40	.20	.35	0.49
Simazine	.5	.30	.70	.25	.15	.35	0.35
	1	.20	.15	.30	.35	.10	0.22
Dacthal	8	.20	.35	.15	.25	.40	0.27
	16	.30	.10	.50	.25	.15	0.26
Zytron	7.5	.85	1.90	.90	.95	.70	1.06
	15	.80	.35	.15	.85	.70	0.57
L-31864	7.5	.20	.35	.30	.40	.85	0.36
	15	.15	.10	.25	.20	.15	0.17

[1]The measurements were made 30 days after seeding.

Table 22. Fresh plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 28 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		3.10	2.40	2.80	2.60	2.90	2.76
Tricazine	2	2.40	3.05	1.85	2.25	2.20	2.35
	4	1.25	1.35	.75	1.00	1.25	1.12
Simazine	.5	.70	1.40	.40	.00	.70	0.64
	1	.00	.00	.30	.10	.15	0.11
Dacthal	8	.25	.05	1.00	.60	1.20	0.62
	16	.15	1.40	.05	.00	.35	1.39
Zytron	7.5	1.70	1.25	1.50	1.30	1.05	1.36
	15	.45	1.85	.45	.00	1.70	0.89
L-31864	7.5	.10	.05	.85	.60	.30	0.38
	15	1.00	.30	1.10	.05	.10	0.51

Table 23. Fresh plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 35 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		3.00	2.70	2.30	2.50	2.75	2.65
Tricazine	2	2.25	2.10	1.80	2.30	2.20	2.13
	4	.35	.60	.50	.40	.50	0.47
Simazine	.5	.70	1.50	1.20	.90	1.20	1.10
	1	.25	.10	.55	.30	.20	0.28
Dacthal	8	.80	.70	1.15	1.30	1.25	1.04
	16	.90	.70	.70	.85	.65	0.76
Zytron	7.5	1.80	2.60	2.30	2.40	2.45	2.31
	15	1.60	2.15	2.15	2.10	2.35	2.07
L-31864	7.5	1.40	1.70	1.20	1.35	.75	1.28
	15	1.05	.80	1.15	1.40	.60	1.00

[1]The measurements were made 30 days after seeding.

Table 24. Dry plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted at the time of herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		.50	.40	.45	.40	.40	0.43
Tricazine	2	.05	.10	.10	.10	.05	0.08
	4	.05	.10	.05	.05	.00	0.05
Simazine	.5	.10	.10	.05	.05	.10	0.08
	1	.05	.05	.05	.00	.00	0.03
Dacthal	8	.00	.15	.20	.10	.10	0.11
	16	.00	.10	.20	.10	.10	0.10
Zytron	7.5	.20	.15	.30	.20	.25	0.22
	15	.00	.15	.00	.20	.15	0.10
L-31864	7.5	.00	.20	.05	.00	.20	0.09
	15	.30	.05	.00	.05	.10	0.10

Table 25. Dry plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 7 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		.45	.30	.45	.35	.30	0.37
Tricazine	2	.15	.15	.10	.15	.10	0.13
	4	.05	.10	.15	.05	.10	0.09
Simazine	.5	.10	.05	.10	.10	.00	0.07
	1	.00	.00	.10	.00	.15	0.05
Dacthal	8	.05	.05	.20	.20	.10	0.12
	16	.05	.10	.15	.10	.15	0.11
Zytron	7.5	.35	.10	.25	.10	.10	0.18
	15	.05	.20	.15	.10	.10	0.12
L-31864	7.5	.00	.25	.05	.10	.25	0.13
	15	.00	.05	.00	.00	.10	0.03

[1] The measurements were made 30 days after seeding.

Table 26. Dry plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 14 days after herbicide treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Control		.50	.40	.55	.45	.60	0.50
Tricazine	2	.15	.15	.20	.20	.20	0.18
	4	.05	.15	.15	.05	.25	0.13
Simazine	.5	.30	.20	.20	.15	.20	0.21
	1	.10	.00	.00	.05	.10	0.05
Dacthal	8	.05	.15	.10	.15	.00	0.09
	16	.15	.05	.15	.10	.10	0.11
Zytron	7.5	.45	.35	.40	.35	.25	0.36
	15	.10	.55	.30	.10	.15	0.24
L-31864	7.5	.25	.20	.20	.10	.35	0.22
	15	.10	.05	.15	.10	.15	0.11

Table 27. Dry plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 21 days after herbicide treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Control		.55	.50	.65	.45	.60	0.55
Tricazine	2	.15	.30	.20	.15	.20	0.20
	4	.05	.10	.05	.00	.10	0.06
Simazine	.5	.05	.10	.05	.00	.05	0.05
	1	.05	.00	.00	.05	.00	0.02
Dacthal	8	.10	.15	.05	.15	.20	0.13
	16	.10	.00	.20	.10	.05	0.09
Zytron	7.5	.25	.50	.30	.50	.20	0.35
	15	.25	.15	.00	.25	.20	0.17
L-31864	7.5	.10	.15	.10	.15	.25	0.15
	15	.05	.00	.15	.10	.05	0.07

[1]The measurements were made 30 days after seeding.

Table 28. Dry plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 28 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		.55	.40	.50	.40	.45	0.46
Trietazine	2	.45	.40	.25	.25	.25	0.32
	4	.20	.15	.10	.20	.20	0.17
Simazine	.5	.15	.20	.10	.00	.10	0.11
	1	.00	.00	.05	.00	.05	0.02
Dacthal	8	.05	.00	.25	.10	.30	0.14
	16	.05	.35	.00	.00	.10	0.10
Zytron	7.5	.50	.25	.45	.45	.25	0.38
	15	.20	.55	.10	.00	.50	0.27
L-31864	7.5	.00	.00	.25	.30	.10	0.13
	15	.45	.05	.35	.00	.00	0.17

Table 29. Dry plant weight measurements[1] in grams of all the aerial portion of the Kanota oat plants in each container planted 35 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		.60	.50	.45	.40	.50	0.49
Trietazine	2	.25	.20	.15	.25	.25	0.22
	4	.05	.25	.15	.30	.20	0.19
Simazine	.5	.25	.55	.35	.25	.35	0.35
	1	.10	.00	.25	.10	.05	0.10
Dacthal	8	.25	.20	.40	.35	.60	0.36
	16	.40	.30	.25	.35	.20	0.30
Zytron	7.5	.40	.60	.45	.50	.50	0.49
	15	.35	.40	.50	.40	.45	0.42
L-31864	7.5	.50	.60	.45	.40	.20	0.43
	15	.30	.25	.40	.45	.15	0.31

[1]The measurements were made 30 days after seeding.

Table 30. Fresh plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted at time of herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.04	.93	1.17	.97	.88	0.998
Trietazine	2	.06	.19	.22	.01	.01	0.098
	4	.17	.22	.06	.06	.05	0.112
Simazine	.5	.28	.31	.13	.04	.13	0.178
	1	.04	.08	.13	.04	.04	0.066
Dacthal	8	.02	.13	.40	.17	.04	0.152
	16	.02	.13	.24	.11	.08	0.116
Zytron	7.5	.22	.11	.40	.13	.24	0.220
	15	.02	.11	.00	.13	.08	0.068
L-31864	7.5	.00	.13	.04	.02	.17	0.072
	15	.33	.04	.02	.04	.13	0.112

Table 31. Fresh plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 7 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.07	.87	1.04	1.02	.98	0.996
Trietazine	2	.37	.40	.22	.27	.24	0.300
	4	.08	.20	.20	.11	.13	0.144
Simazine	.5	.18	.13	.29	.27	.02	0.178
	1	.04	.04	.22	.04	.22	0.112
Dacthal	8	.08	.08	.31	.31	.13	0.182
	16	.02	.13	.27	.13	.20	0.150
Zytron	7.5	.31	.11	.27	.13	.08	0.180
	15	.08	.35	.33	.13	.15	0.208
L-31864	7.5	.02	.60	.08	.31	.65	0.332
	15	.00	.04	.00	.02	.25	0.062

[1]The measurements were made 30 days after seeding and are expressed as the per cent of the mean for the control containers.

Table 32. Fresh plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 14 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.08	.81	1.11	.89	1.09	0.996
Tricazine	2	.41	.57	.63	.59	.65	0.570
	4	.04	.41	.32	.10	.57	0.288
Simazine	.5	.63	.41	.20	.51	.75	0.500
	1	.12	.00	.00	.12	.16	0.080
Dacthal	8	.08	.16	.08	.14	.02	0.096
	16	.12	.08	.16	.14	.10	0.120
Zytron	7.5	.52	.48	.51	.48	.47	0.492
	15	.12	.75	.47	.10	.18	0.324
L-31864	7.5	.48	.39	.32	.10	.67	0.390
	15	.08	.06	.14	.10	.16	0.108

Table 33. Fresh plant weight measurements[1] of all aerial portions of Kanota oat plants in each container, planted 21 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		.95	1.03	1.12	.84	1.04	0.996
Tricazine	2	.32	.55	.28	.13	.49	0.354
	4	.19	.38	.15	.08	.13	0.186
Simazine	.5	.11	.26	.09	.05	.13	0.128
	1	.07	.05	.11	.13	.03	0.078
Dacthal	8	.07	.13	.05	.09	.15	0.098
	16	.11	.03	.19	.09	.05	0.094
Zytron	7.5	.32	.72	.34	.36	.26	0.400
	15	.30	.13	.05	.32	.26	0.212
L-31864	7.5	.07	.13	.11	.16	.32	0.158
	15	.05	.03	.09	.07	.05	0.058

[1]The measurements were made 30 days after seeding and are expressed as the per cent of the mean for the control containers.

Table 34. Fresh plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 28 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.12	.87	1.01	.94	1.05	0.998
Trietazine	2	.87	1.10	.67	.81	.80	0.850
	4	.45	.49	.27	.36	.45	0.404
Simazine	.5	.25	.51	.14	.00	.25	0.230
	1	.00	.00	.11	.03	.05	0.038
Dacthal	8	.09	.01	.36	.22	.43	0.222
	16	.05	.50	.01	.00	.12	0.136
Zytron	7.5	.61	.45	.54	.47	.38	0.490
	15	.16	.67	.16	.00	.61	0.320
L-31864	7.5	.03	.01	.30	.21	.11	0.132
	15	.36	.11	.39	.10	.03	0.198

Table 35. Fresh plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 35 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.13	1.02	.87	.96	1.04	1.004
Trietazine	2	.85	.79	.68	.87	.83	0.804
	4	.13	.22	.18	.15	.18	0.172
Simazine	.5	.26	.56	.45	.33	.45	0.410
	1	.09	.03	.21	.11	.07	0.102
Dacthal	8	.30	.26	.43	.49	.47	0.390
	16	.33	.26	.26	.32	.24	0.282
Zytron	7.5	.66	.98	.86	.90	.92	0.864
	15	.60	.81	.81	.79	.88	0.778
L-31864	7.5	.53	.64	.45	.51	.28	0.482
	15	.39	.30	.43	.53	.22	0.374

[1]The measurements were made 30 days after seeding and are expressed as the per cent of the mean for the control containers.

Table 36. Dry plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted at time of herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.16	.93	1.05	.93	.93	1.000
Trietazine	2	.12	.23	.23	.23	.12	0.186
	4	.12	.23	.12	.12	.00	0.118
Simazine	.5	.23	.23	.12	.12	.23	0.186
	1	.12	.12	.12	.00	.00	0.072
Dacthal	8	.00	.35	.46	.23	.23	0.254
	16	.00	.23	.46	.23	.23	0.230
Zytron	7.5	.46	.35	.72	.46	.58	0.510
	15	.00	.35	.00	.46	.35	0.232
L-31864	7.5	.00	.46	.12	.00	.46	0.208
	15	.70	.12	.00	.12	.23	0.234

Table 37. Dry plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 7 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.22	.81	1.22	.95	.81	1.002
Trietazine	2	.41	.41	.27	.41	.27	0.354
	4	.14	.27	.41	.14	.27	0.246
Simazine	.5	.27	.14	.27	.27	.00	0.190
	1	.00	.00	.27	.00	.41	0.136
Dacthal	8	.14	.14	.54	.54	.27	0.326
	16	.14	.27	.41	.27	.41	0.300
Zytron	7.5	.95	.27	.68	.27	.27	0.488
	15	.14	.54	.41	.27	.27	0.326
L-31864	7.5	.00	.68	.14	.27	.68	0.354
	15	.00	.14	.00	.00	.27	0.082

[1]The measurements were made 30 days after seeding and are expressed as the per cent of the mean for the control containers.

Table 38. Dry plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 14 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.00	.80	1.10	.90	1.20	1.000
Tricazine	2	.30	.30	.40	.40	.40	0.360
	4	.10	.30	.30	.10	.50	0.260
Simazine	.5	.60	.40	.40	.30	.40	0.420
	1	.20	.00	.00	.10	.20	0.100
Dacthal	8	.10	.30	.20	.30	.00	0.180
	16	.30	.10	.30	.20	.20	0.220
Zytron	7.5	.90	.70	.80	.70	.50	0.720
	15	.20	1.10	.60	.20	.30	0.480
L-31864	7.5	.50	.45	.40	.20	.70	0.450
	15	.20	.10	.30	.20	.30	0.220

Table 39. Dry plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 21 days after herbicide treatment.

Chemicals (ppmw)		Replications 1	2	3	4	5	Mean
Control		1.00	.91	1.18	.81	1.09	0.998
Tricazine	2	.27	.54	.36	.27	.36	0.360
	4	.09	.18	.09	.00	.18	0.108
Simazine	.5	.09	.18	.09	.00	.09	0.090
	1	.09	.00	.00	.09	.09	0.036
Dacthal	8	.18	.27	.09	.27	.36	0.234
	16	.18	.00	.36	.18	.09	0.162
Zytron	7.5	.45	.91	.54	.91	.36	0.634
	15	.45	.27	.00	.45	.36	0.306
L-31864	7.5	.18	.27	.18	.27	.45	0.270
	15	.09	.00	.27	.18	.09	0.126

[1]The measurements were made 30 days after seeding and are expressed as the per cent of the mean for the control containers.

Table 40. Dry plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 28 days after herbicide treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Control		1.19	.87	1.08	.87	.98	0.998
Trietazine	2	.98	.87	.54	.54	.54	0.694
	4	.43	.32	.22	.43	.48	0.376
Simazine	.5	.32	.43	.22	.00	.22	0.238
	1	.00	.00	.11	.00	.11	0.044
Dacthal	8	.11	.00	.54	.22	.66	0.306
	16	.11	.76	.00	.00	.22	0.218
Zytron	7.5	1.08	.54	.98	.98	.54	0.824
	15	.43	1.19	.22	.00	1.08	0.584
L-31864	7.5	.00	.00	.54	.65	.22	0.282
	15	.98	.11	.76	.00	.00	0.370

Table 41. Dry plant weight measurements[1] of all aerial portion of Kanota oat plants in each container, planted 35 days after herbicide treatment.

Chemicals	(ppmw)	Replications 1	2	3	4	5	Mean
Control		1.22	1.02	.92	.82	1.02	1.000
Trietazine	2	.50	.40	.30	.50	.50	0.440
	4	.10	.50	.30	.60	.40	0.380
Simazine	.5	.50	1.10	.71	.50	.70	0.702
	1	.20	.00	.50	.20	.10	0.200
Dacthal	8	.50	.40	.80	.70	1.20	0.720
	16	.80	.60	.50	.70	.40	0.600
Zytron	7.5	.80	1.20	.90	1.00	1.00	0.980
	15	.70	.80	1.00	.80	.90	0.840
L-31864	7.5	1.00	1.20	.90	.80	.40	0.860
	15	.60	.50	.80	.90	.30	0.620

[1]The measurements were made 30 days after seeding and are expressed as the per cent of the mean for the control containers.

SOIL RESIDUE EFFECTS OF SELECTED PRE-EMERGENCE HERBICIDES AS MEASURED BY THE GROWTH OF KANOTA OATS

by

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The phytotoxic soil residues of 2-chloro-4-ethylamino-6-diethylamino-s-triazine (trietazine), 2-chloro-4,6-bis(ethylamino)-s-triazine (simazine), dimethyl 2,3,5,6-tetrachloroterephthalate (dacthal), O-2,4-dichlorophenyl O-methylisopropylphosphoramidothioate (zytron), N,N-di(n-propyl)-2,6-dinitroaniline (L-31864), N,N-dimethyl-α-α-diphenylacetamide (diphenamid) were measured by the growth of Avena sativa L., var. Kanota, the bioassay plant. Treatments of each herbicide at 2 rates each were applied to containers holding 500 gram samples of an alluvial fine sandy loam soil. The bioassay plant was seeded at weekly intervals starting with the date of herbicide application.

Visual observations were made daily, and at the end of the 30 day growing period, plant counts and weight measurements of the aerial portions of the bioassay plants were made. The herbicides applied produced the following injury symptoms in the bioassay plant: (a) trietazine and simazine injury was characterized by the basipetal development of chlorotic and necrotic tissues in the established seedlings; (b) dacthal injury was evidenced by retarded development or dwarfing malformation of the leaf blade, and presence of necrotic spots in the true leaves of the seedling; (c) zytron applications caused the same injury symptoms described for dacthal, and in addition, abnormal swelling of the second internode occurred in severely injured seedlings; (d) typical L-31864 injury was observed as a general lack of seedling growth and development past emergence from the soil; and, (e) diphenamid applications resulted in the death of all oat seedlings in containers treated with this herbicide.

The relative life spans of toxic soil residues from the herbicide treatments were determined by use of plant counts and dry plant weight

measurements to be as follows: (a) about 40 days for zytron at 7.5 ppmw; (b) about 60 days for trietazine at 2 ppmw, dacthal at 8 and 16 ppmw, and zytron at 15 ppmw, and L-31864 at 7.5 ppmw; and, (c) in excess of 60 days for trietazine at 4 ppmw, simazine at .5 and 1 ppmw, L-31864 at 15 ppmw, and diphenamid at 5 and 10 ppmw.

A system of classification for pre-emergence herbicides based upon their time of herbicidal action in relation to seedling growth was proposed as follows: (a) chemicals that kill the seed or seedling prior to emergence of the coleoptile shoot from the soil, i.e., diphenamid; (b) chemicals that retard the growth and development of the emerged seedling, and kill it prior to its establishment, i.e., dacthal, zytron and L-31864; and, (c) chemicals that kill the seedlings after they are established as result of the toxic action of the accumulated herbicidal chemical in the plant tissues, i.e., trietazine and simazine.